Learned and cued distractor rejection for multiple features in visual search

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Abstract

Ignoring distracting information is critical for effective visual search. When individuals are cued to ignore a stimulus, they first attend the to-be-ignored stimulus *before* learning to reject it. Individuals can learn to overcome the initial distraction produced by the explicit cues, although this cued distractor rejection appears for only one distractor feature. Multiple distractor colors cannot be rejected effectively, even with extensive experience. We asked if this apparent limit on distractor rejection was caused by a restriction on the number of different features (i.e., colors) that could be learned and rejected as distractors. To explore this potential capacity limitation, we asked if attention can learn to reject the smallest possible number of multiple distractors, namely, two. In four experiments examining cued distractor rejection, individuals searched through heterogeneously colored arrays containing reliable, non-target color information. In Experiments 1 and 2, we explicitly cued individuals with which of two colors (both colors in Experiment 1 or one color in Experiment 2) could be safely ignored. Cued distractors were not reliably rejected, replicating previous findings. Additionally, in Experiment 2, we presented a to-be-ignored color without explicit cues and we found that these “uncued” distractors were reliably rejected. In Experiments 3 and 4, we presented the to-be-ignored color information without explicit cues; individuals learned to reliably ignore multiple distractor colors without explicit cueing. These results suggest that learned distractor rejection is better suited to experience-driven learning than explicitly cued distractor learning: Explicit cueing reliably interferes with learned distractor rejection.

Keywords Visual search · Attention: Selective · Attention

Introduction

We are observers in a dynamic and complex environment. Our visual systems are fed more information than they can efficiently process at once. To help mitigate the capacity limitations of the system, our visual attentional systems selectively process a subset of the information, and filter out the rest. Almost every theory of visual attention posits that selection is driven by selection for a target amongst distracting information (e.g., Bundesen, 1990; Desimone & Duncan, 1995; Treisman, 1998; Wolfe, 1994). Historically, most of the research on visual attention has focused on selection of task-relevant stimuli, namely, orienting attention toward targets. Recently, there has been a push to examine the other critical piece of attentional selection: how the system ignores

distracting information (Beck, Luck, & Hollingworth, 2018; Cunningham & Egeth, 2016; Moher & Egeth, 2012; Vatterott, Mozer, & Vecera, 2018; Vatterott & Vecera, 2012; Woodman & Luck, 2007; for review see Gaspelin & Luck, 2018). The aim of the current study was to examine how the visual attentional system learns to overcome distraction. More specifically, the current study was designed to examine the interaction between explicit cueing and the implicit learning of distracting information in a visual search task.

Target templates guide visual search (e.g., Desimone & Duncan, 1995; Wolfe, 1994), and these templates can guide attention from either visual working memory or visual long-term memory (Woodman, Carlisle, & Reinhart, 2013). Can the formation of distractor templates also facilitate search? The notion of a negative or distractor template, or template for rejection, has been used to argue that knowledge of upcoming distractor features facilitates search for a target (e.g., Woodman & Luck, 2007). In other words, if the system knows which stimuli to avoid, the system can configure attentional allocation more efficiently to locate the target. There have been mixed sources of evidence supporting templates for

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rejection. Woodman and Luck (2007) have provided some of the more consistent evidence in support of a template for rejection in a dual, visual search/memory task. Participants were tasked with remembering a color in visual working memory (VWM) for subsequent recall. During the working memory retention interval, participants performed a visual search task: they searched for and responded to a uniquely oriented Landolt C, amongst heterogeneously colored distractors (Landolt Cs). Importantly, the search target never matched the color of the item held in memory. Further, the number of search distractors that matched the color of the item in VWM varied. If the nontarget item in memory could be used to reject items during visual search, then search should have been faster as the number of distractors matching the color in memory increased, because more distractors could be rejected from search. Mean RTs were reliably faster for increasingly larger numbers of color matching distractors; thus, participants were faster to respond to the target when distractors matched a color held in VWM, providing evidence for a VWM-based template for distractor rejection.

Other research has further explored the role of templates for rejection, specifically by explicitly cueing the features associated with distractors, prior to search. Arita, Carlisle, and Woodman (2012) examined the role of cueing a color before a visual search display that contained two colors. In different blocks of trials, the color cue could perfectly predict the target color (a “positive” cue), could perfectly predict the distractor color (a “negative” cue), or could be different from the two colors in the search display, thereby not predicting either the target or distractor colors (a “neutral” cue). Participants benefitted from both positive and negative cues, responding faster in these conditions than in the baseline neutral cue condition. Subsequent findings have suggested that the benefit for negative cues is due to a spatial recoding mechanism (Beck & Hollingworth, 2015). Others, however, have found similar patterns of distractor rejection following a negative cue not attributable to spatial recoding, provided participants have sufficient time to reject a distractor (e.g., Moher & Egeth, 2012).

A finer-grained pattern emerges when distractor colors are cued prior to a search display. Specifically, providing explicit cues for distractor features has a negative effect on search efficiency initially; a cued distractor feature (e.g., color) initially captures attention before that item is eventually rejected (Cunningham & Egeth, 2016; Moher & Egeth, 2012). Moher and Egeth (2012), proposed that the visual system uses a template for rejection to “search and destroy” distractors. First, attention is biased toward distractors that match the cued-to-ignore feature (the “search” in “search and destroy”), and attention then marks that distractor as an item to be rejected (“destroy”). If the visual system is provided enough time through a sufficient stimulus onset asynchrony (SOA) between the cue and search array, then search for the target is

more efficient because the cued distractor color is fully rejected. A conceptually similar pattern has been demonstrated using oculomotor capture; early oculomotor capture is followed by later avoidance within a trial, in response to a negative cue (Beck, Luck, & Hollingworth, 2018). Critically, these forementioned studies all have used trial-unique or variable distractor cueing, in which the cued distractor color varies from one trial to the next. Although this procedure permits within-trial distractor rejection, it does not speak to the establishment of longer term distractor rejection.

Distractor rejection also can be learned on a long-term basis. If a distractor color is cued but does not change on a trial-by-trial basis and, instead, remains a distractor color throughout the experiment, the visual attentional system is able to learn to reject that color (Cunningham & Egeth, 2016; Moher, Lakshmanan, Egeth, & Ewen, 2014). For example, Cunningham and Egeth (2016) provided explicit, written “ignore” cues (e.g., “Ignore Red”) for distractor features in a visual search task. Early in the experiment, providing valid information about the upcoming distractor features hurt performance by slowing response times compared to a neutral cue baseline condition. The slowed responses to the cued distractor color was termed an attentional “white bear” effect (also see Tsal & Makovski, 2006; Wegner, Schneider, Carter, & White, 1987). Over the course of the experiment, however, participants learned to overcome the initial distraction associated with the ignore cue and produced reliable distractor rejection. By the end of the experiment, participants were faster to find a target preceded by an ignore cue than by a neutral cue (Cunningham & Egeth, 2016).

Although explicit “ignore” cues appear to allow participants to reject the cued item during visual search, Cunningham and Egeth (2016) uncovered an important limitation to this cued distractor rejection: Participants were unable to reject different distractors on a trial-by-trial basis. That is, ignore cues appeared on half of the trials, and if those cues directed participants to reject any of the 12 colors that appeared in the search array, then compared to neutral cues, which appeared on the other half of trials, trial-unique ignore cues failed to produce any distractor rejection across the course of the experiment (Cunningham & Egeth, 2016, Experiment 2a). Conversely, under similar experiment conditions when only a single color was cued on half of the trials, ignore cues initially produced distraction (the “white bear” effect), followed by robust distractor rejection (Cunningham & Egeth, 2016, Experiment 2b).

In contrast to the inability to reject multiple distractors from an explicit “ignore” cue, other studies have demonstrated that participants can reject multiple distractors. During visual search for a target among heterogeneous distractors – a so-called “feature search” – a color singleton distractor does not slow response times in the aggregate (Bacon & Egeth, 1994). However, during feature search, robust distraction occurs

early in an experiment when the singleton distractor appears initially, followed by efficient distractor rejection that emerges with experience (Vatterott & Vecera, 2012; also see Gaspelin, Leonard, & Luck, 2017; Zehetleitner, Goschy, & Müller, 2012). Most relevant, different colored singleton distractors can be rejected when they are intermixed within a block of trials (Vatterott et al., 2018). That is, when three different singleton distractor colors appear intermixed within a block, participants can nevertheless learn to reject those distractors with enough trials of experience.

What causes the discrepancy between explicitly cued distractor rejection and implicitly learned rejection? One plausible possibility lies in a general capacity limitation for the number of distractor items that can be learned to be ignored. That is, the number of colors that were rejected in the foregoing studies differed, and this difference might underlie the apparent discrepancies across studies. Specifically, when Cunningham and Egeth (2016) presented trial-unique “ignore” cues, there were 12 different to-be-ignored colors, but in Vatterott et al.’s (2018) learned distractor rejection, there were only three to-be-ignored colors. If there is a limitation on all distractor rejection in which only a relatively small set of features can be learned as non-target distractors, then distractor rejection would be absent with a large set of distractors. The 12 distractor colors cued by Cunningham and Egeth (2016) might have exceeded the effective distractor “set size,” whereas the three colors learned as distractors by Vatterott et al.’s (2018) participants might have been well within the effective range of a distractor rejection mechanism.

In contrast to a general capacity limit for all distractor rejection, trial-unique “ignore” cues might prevent or slow the conversion from a positive search template to a template for rejection. The presentation of an ignore cue, such as “Ignore Red” initially biases attention toward matching (i.e., red) items both in the early phases of an experiment (Cunningham & Egeth, 2016) and in the early phases of an individual trial (Beck et al., 2018; Moher & Egeth, 2012). With sufficient learning across an experiment or time within a trial, the bias toward matching items is reversed to an avoidance, or rejection, of those items. There may exist a severe bottleneck on whatever process(es) is associated with controlling this conversion, where only a single distractor item can be effectively negated. This limitation in translating from a bias toward a cued distractor to away from that distractor could be related to recent accounts in which only a single attentional template can guide attention at a time (Olivers, Peters, Houtkamp, & Roelfsema, 2011).

In the current experiments, we ask if distractor rejection is limited primarily by a general capacity limitation on the number of potential distractor colors that can be rejected or by preventing the conversion of multiple items from a bias toward cued items to away from those items. We first ask if as few as two distractor colors can be rejected using explicit

“ignore” cues. Participants searched for a target following either a neutral cue or one of two ignore cues (“ignore red” or “ignore green”). If general capacity limits on the number of items that can be rejected, then reducing the number of cued distractor items should allow participants to learn to reject those distractors as in previous research (Vatterott et al., 2018). Specifically, we would predict that early in the experiment, participants would exhibit an initial bias toward the cued distractor color, producing a white-bear distraction effect. Later in the experiment, however, participants should effectively reject two cued distractors. In contrast, if cueing multiple distractor items – even as few as two – delays or prevents the conversion from a positive template to a rejection template, then participants may be unable to reliably reject as few as two cued distractors. Such an account would replicate previous results in which participants exhibited an initial “white bear” bias toward the cued distractor item, but there would be no reliable distractor rejection (Experiment 2a, Cunningham & Egeth, 2016).

To preview our results, Experiment 1 demonstrated that participants were unable to reject even as few as two distractor colors over the course of the experiment, suggesting a severe limitation on the translation from a bias toward the cued distractor item to away from the cued distractor item. Because of differences between the search task we used in Experiment 1 and those demonstrating learned rejection for multiple distractors (Vatterott et al., 2018), in Experiments 2 and 3 we showed learned distractor rejection for multiple distractor items in the same displays with the same task. Taken together, these results indicate that cueing an upcoming distractor is inefficient for producing robust distractor rejection, likely because of the deleterious biasing effects that the cue produces toward the cued distractor.

General method

The current study used a conceptually similar design to Experiment 2b of Cunningham and Egeth (2016). Each experiment consisted of a visual search task using a set size of eight, which was always preceded by a text cue. When the cue told participants which color to ignore (Ignore trials), the target could not be that color. When the cue said “Neutral” (Neutral trials) any item could be any color, with the exception that the cued-to-be-ignored color was not present in the display. The target stimuli were consistent across all three Experiments (i.e., search for the “B” or “X”). All experiments contained search displays with two majority colors: more than one item was homogeneously colored, whereas the rest were heterogeneously colored (see Fig. 1). Experiments 1–4 all used two majority colors on every trial. This design encouraged distractor rejection by providing multiple stimuli in the to-be-ignored color. As a result, there were four potential

Fig. 1 General method for all experiments. All trials began with the presentation of a cue that either told participants (100% validity) which color could be ignored on that trial (e.g., “Ignore Red”) or said the word “Neutral.” Every display contained eight colored capital letters: Participants always searched for a target letter (B or X) amongst distractor letters. Every trial contained two majority colors, and two non-majority colors: three items were one color, three items were another color, and the remaining two items were both different colors. The various majority color contingencies are discussed in detail in the Method section of each Experiment

effective set sizes (number of colored items the target could be): set size of eight (Neutral trials where any item could be any color), set size of five (Experiments 1–4; one majority distractor color), or a set size of two (Experiment 4; two majority distractor colors).

Experiment 1

As noted previously, cued distractor rejection can be observed for one explicitly cued distractor feature (Cunningham & Egeth, 2016, Experiments 1 and 2b). Knowing that the system can reject one feature if explicitly cued, our aim in Experiment 1 was to determine whether the system can reject multiple distractor features (i.e., colors) using explicit distractor cues. We predicted that if the system can reject multiple distractors through explicit cueing, the system should be able to reject at least two distractor features. If true, then we should observe initial distraction (the “white-bear effect”) followed by later distractor rejection for *both* cued colors. Distractor rejection would appear as faster response times following ignore cues than neutral cues, because ignore cues would allow items to be disregarded by attention, effectively reducing the display’s set size. Alternatively, if the system cannot reject multiple distractor features through explicit cueing, then we should observe initial distraction (the “white-bear effect”), but there should be no learned distractor rejection. This latter finding would replicate previous work with multiple cued colors that demonstrated no reliable distractor rejection across the course of the experiment (Cunningham & Egeth, 2016, Experiment 2a).

Method

Participants

We recruited 26 naïve University of Iowa undergraduate students (mean age = 19.2 years; 15 female, 11 male) from introductory psychology courses with normal or corrected-to-normal visual acuity and normal color vision to participate in the experiment. We conducted a power analysis using N^* (Cohen, 1988): using an effect size of 0.2 (Cunningham & Egeth, 2016), which indicated that 26 participants would be needed to obtain 80% power: We stopped data collection at 26 participants. Participants gave informed consent and received course credit upon completion. The University of Iowa Institutional Review Board approved the experimental protocol.

Apparatus

All three experiments were performed using the same apparatus. All experiments were presented using MATLAB (The MathWorks, Natick, MA, USA) and the Psychophysics Toolbox software (Brainard, 1997) running on a Macintosh Mini computer. Stimuli were presented on a 23-in. LED monitor (resolution of $1,280 \times 720$ pixels) with participants seated approximately 60 cm from the display.

Stimuli

The search display consisted of a centrally presented fixation cross (subtending 0.51° visual angle) surrounded by colored English alphabet letters (Ariel, 36-point font). The target letter, either a “B” or “X” and distractor letters “D, K, N, P, R, S, and F,” each subtended a $0.51^\circ \times 0.51^\circ$ visual angle. We chose these distractor letters because they shared similar features as the target (curved parts, straight diagonal lines, etc.). All stimuli were equidistant from fixation, placed around an imaginary circle (with 45° separating each letter) at an eccentricity of 3.03° visual angle. Each display contained four colors, chosen from a pool of six colors: red (RGB: 255, 0, 0), blue (RGB: 0, 85, 255), green (RGB: 0, 255, 0), yellow (RGB: 255, 225, 20), pink (RGB: 255, 0, 127), and orange (RGB: 255, 86, 13). Each display contained two majority colors (three of the eight stimuli were one color, three were another color), and two filler colors (each of the two remaining items were a different color). All stimuli were presented on a black (RGB: 0, 0, 0) background, and all text (including the cues) was rendered in white (RGB: 255, 255, 255). The cue display consisted of white text presented approximately 1.26° visual angle above fixation, and between 2.39° and 4.00° visual angle horizontally, in Ariel, 30-point font.

Design and procedure

Each trial began with a white-text cue presented above fixation for 1,000 ms. The cue (100% valid) told participants the type of upcoming trial. Half of all trials were Ignore trials, and the other half were Neutral trials. For each participant, two colors were randomly selected, at the beginning of the experiment, from the pool of six colors, to be the two cued colors. On ignore trials, the cue told participants which of the two cued colors they could safely ignore (which color the target was not going to be: e.g., “Ignore Blue”). Ignore trials were evenly split between cueing the two cued colors. On an Ignore trial, one of the two majority colors (one set of three homogenously colored stimuli) was the to-be-ignored color (i.e., blue, if a participant was cued “Ignore Blue”), the other majority color was one of the filler colors (randomly selected). Each Ignore trial contained one cued color; the other cued color was absent from the display. The target was never either to-be-ignored (cued) color. The rest of the stimuli were randomly assigned the remaining four filler (non-cued) colors. On each trial, the target was either presented in the other majority color (the other three homogenously colored items) or one of the remaining two filler colors. This ensured that participants wouldn’t simply ignore the majority color on each trial, because, on half of the trials, the target was the non-cued majority color.

On neutral trials, participants were first presented with the text “Neutral.” Neither cued color was presented on Neutral trials. Displays were identical to Ignore trials, except that any item could be any of the four filler colors. Therefore, the target could be any of the four colors, and could be in a majority color or not. For both Ignore and Neutral trials, the target and distractor letters were randomly dispersed around the imaginary circle. As a result, the majority of colored stimuli were randomly grouped on each trial.

Following the cue, the fixation cross remained on screen for 1,000 ms before the search display was presented. The search display (eight colored letters) appeared and remained on screen until response. Participants were tasked with locating and responding to the target identity (“B” or “X”) by pressing either the “Left Shift” or “Right Shift” key (target-response assignments counterbalanced across participants) as quickly and accurately as possible. Inter-trial intervals were controlled by the participant (they would press a button to indicate they were ready for the next trial). No feedback was provided during the experiment. Participants completed four blocks of 160 trials each (640 trials total). Fifty percent of all trials were Ignore trials (25% for each cued color) and 50% were Neutral trials, randomly intermixed throughout each block.

Participants performed 16 practice trials to learn the target-response button pairings. During practice, trials were identical to the experiment except all stimuli were white, and the cue

was always Neutral. Feedback was provided: “Correct!” and “Incorrect!” were presented in white at fixation following correct and incorrect responses respectively.

Results and discussion

We removed response times (RTs) that were faster than 100 ms, slower than 2,500 ms, and more than 2.5 standard deviations above or below each participant’s condition means, which resulted in the elimination of 5.81% of trials. We further removed inaccurate trials from data analysis, which eliminated 3.04% of all trials. Therefore, we removed 8.86% of all trials. To assess the effect of experience we divided the data into four blocks (160 trials each).

To analyze the effects of experience on the ability to reject a cued distractor, we performed a 2 (cue type: Ignore vs. Neutral) $\times$ 4 (block) repeated measures ANOVA on mean RTs.¹ The mean RTs are given in Table 1, and the distraction scores (ignore trial RTs minus neutral trial RTs) are shown in Fig. 2. As seen in Fig. 2, we observed a robust white bear effect; namely, participants were slowed on Ignore trials compared to Neutral trials in the early blocks of the experiment. However, we did not observe reliable distractor rejection, which would appear as negative distraction differences in Fig. 2.

These observations were corroborated by our statistical analyses. We observed a significant main effect of cue type, $F(1,25) = 11.057$, $p = .003$, $\eta_p^2 = .307$, with slower mean RTs on Ignore (969 ms) than Neutral (936 ms) trials; we also observed a significant main effect of block, $F(3,75) = 25.700$, $p < .001$ (Huynh-Feldt corrected), $\eta_p^2 = .507$, indicating that mean RTs decreased over the course of the experiment. Critically, we observed a significant interaction between cue type and block, $F(3,75) = 5.412$, $p = .005$ (Huynh-Feldt corrected), $\eta_p^2 = .178$. We followed up the interaction by examining the simple main effects of cue type for each block. Mean RTs were significantly slower on Ignore (1,095 ms) than Neutral (1,015 ms) trials in Block 1, $p < .001$, $\eta_p^2 = .445$; mean RTs were significantly slower on Ignore (962 ms) than Neutral (928 ms) trials in Block 2, $p = .013$, $\eta_p^2 = .221$; critically, mean RTs were not significantly different between Ignore (915 ms) than Neutral (920 ms) trials in Block 3, $p = .811$, $\eta_p^2 = .002$ nor in Block 4 (Ignore – 901 ms, Neutral – 881 ms), $p = .161$, $\eta_p^2 = .077$. Therefore, we observed initial distraction to the cued color (“white-bear effect” in Blocks 1 and 2) that disappeared, but did not turn into distractor rejection (Blocks 3 and 4). Ignore cue trials were not significantly

¹ We collapsed the two Cued conditions, because we initially performed a 2 (cue type: Ignore Color A vs. Ignore Color B) $\times$ 4 (Block) repeated measures ANOVA on mean RTs. Critically, we found no main effect of cue type, $F(1,25) = .481$, $p = .993$, nor a significant interaction between cue type and block, $F(3,75) = .171$, $p = .915$, indicating that there was no difference between the two ignore conditions, allowing us to collapse across both.

Table 1 Mean response times (RTs; in ms, top half) and accuracy (lower half) for Experiment 1. Standard deviations are given in parentheses

Trial type	Block 1	Block 2	Block 3	Block 4
Ignore (RT)	1099 (384)	963 (347)	915 (341)	902 (337)
Neutral (RT)	1015 (378)	928 (333)	921 (340)	882 (325)
Ignore (Acc.)	97% (.13)	97% (.13)	96% (.14)	96% (.15)
Neutral (Acc.)	97% (.12)	97% (.15)	96% (.17)	96% (.15)

faster than neutral cue trials, in contrast to other work demonstrating efficient distractor rejection (Cunningham & Egeth, 2016; also see Stilwell & Vecera, 2017).

Individual color analyses

To examine whether participants were unable to reject either distractor color, particularly in the later blocks (Blocks 3 and 4), we conducted follow-up analyses to determine whether participants were learning to reject only one of the two colors, which would fail to emerge in the previous analyses. To be clear, the possibility remains that some participants learned to reject one of the two colors and were distracted by the other, while other participants showed the reverse pattern; therefore,

we would fail to observe learned distractor rejection in the later blocks because the two effects (cued distraction and learned distractor rejection) would effectively cancel each other out. To address this possibility, we determined which of the two colors, for each participant, was the more interfering color (i.e., the color that produced slower mean RTs when it was present than absent) and which color was the less interfering color (i.e., the color that produced faster mean RTs when it was present than absent); more interference is analogous to cued distraction and less interference is analogous to learned distractor rejection. After identifying the more and less interfering colors, respectively, for each participant, we then performed a two-factor, repeated measures ANOVA on mean RTs, with distractor condition (more interfering color present vs. less interfering color present vs. neither distractor color present) and block (Blocks 3 and 4) as factors. We observed a trending main effect of distractor condition, $F(2,50) = 2.778$, $p = .072$, $\eta_p^2 = .100$, which was driven primarily by numerically slower mean RTs on trials containing the more interfering color (929 ms) than trials containing the less interfering color (887 ms), $p = .093$; further, there were no other differences in mean RTs between the three distractor conditions (all p 's $> .508$). There was a main effect of block, $F(1,25) = 7.949$, $p = .009$, $\eta_p^2 = .241$, with slower mean RTs in Block 3 than in Block 4. Additionally, there was no interaction between

Fig. 2 Experiment 1 results. The differences between mean response times (RTs) on Ignore trials and Neutral trials (Ignore – Neutral) as a function of Block are plotted. Positive values indicate increased distraction by the cued-to-be-ignored color; negative values indicate

increased distractor rejection. Differences are plotted within the bars for convenience. Error bars reflect 95% confidence intervals between the difference scores and zero (Cousineau, 2005; Morey, 2008)

distractor condition and block, $F(2,50) = 2.013$, $p = .144$, $\eta_p^2 = .075$, suggesting that neither distractor color produced cued distraction nor learned distractor rejection across either of the later blocks. These analyses suggest that participants were not learning to reject *either* of the two colors. Specifically, mean RTs were not faster on trials with either distractor color present than absent. The more interfering color tended to slow mean RTs relative to trials where no distractor color was present. Further, mean RTs on trials containing the less interfering color were no different than trials without either distractor color present. Based on this analysis, we conclude that participants were not learning to ignore *either* distractor color following explicit cues. When presented with two possible (cued) color distractors to ignore or reject, participants appear unable to learn to reject both of those distractor colors.

Accuracy

We performed the same analysis of accuracy that we used for mean RTs. We performed a 2 (cue type: Ignore vs. Neutral) $\times$ 4 (block) repeated measures ANOVA on mean accuracy. There was neither a significant main effect of cue type, $F(1,25) = 1.146$, $p = .295$, $\eta_p^2 = .044$, of block, $F(3,75) = 2.086$, $p = .124$ (Huynh-Feldt corrected), $\eta_p^2 = .077$, nor a significant interaction between cue type and block, $F(3,75) = .587$, $p = .625$, $\eta_p^2 = .023$. Therefore, our data suggest no speed-accuracy trade-off.

Experiment 1 demonstrated that the system cannot reject multiple distractor features (i.e., colors) using explicit distractor cues, despite using the smallest number of distractor features: two. We replicated initial distraction (i.e., the “white-bear effect”: slower mean RTs on Ignore than Neutral trials in Block 1) from previous work (e.g., Cunningham & Egeth, 2016; Stilwell & Vecera, 2017), but, critically the observed distraction effects persisted throughout the experiment for both cued colors. We failed to observe any distractor rejection effects (i.e., faster mean RTs on Ignore than Neutral trials) throughout the experiment. Failing to observe reliable distractor rejection replicates previous work with multiple explicitly cued features (Cunningham & Egeth, 2016, Experiment 2a). Our results point to a dramatic bottleneck on the ability to convert from a white bear bias toward the cued distractor to a bias to avoid that cued distractor. Visual attention seems capable of only rejecting one distractor feature when explicitly cued. However, individuals may have failed to learn to reject both cued distractor colors because they did not have sufficient experience with those colors. In previous work (Cunningham & Egeth, 2016), individuals only had to learn to reject one color, whereas in our Experiment 1, participants had to learn to reject two. As a result, in our Experiment 1, participants had approximately half as many trials to learn each distractor color as the participants in Cunningham and Egeth’s (2016) Experiment 1. Therefore, we cannot conclude

that individuals are unable to learn to reject multiple colors; perhaps, individuals need more experience to learn to reject multiple, cued distractor colors.

Experiment 2

We failed to observe distractor rejection for two explicitly cued distractor features in Experiment 1. The lack of distractor rejection with multiple cued features is unlikely to be due to a minimum capacity limitation on the number of items that can be ignored. This capacity limitation would mean that attention can only learn to reject one feature at a time. Instead of a capacity on the number of features that can be rejected, we hypothesize that explicit cues interfere with effective distractor rejection because the presence of a color word in the cue initially biases attention toward matching items, and some other process must flip or negate this bias. This change-over between biases has been conceptualized as a conversion from a positive template to an exclusionary template, or template for rejection (see Beck et al., 2018). Further, we suggest that it is the nature of this conversion, or cued distraction, that prevents learned distractor rejection, not a lack of experience with the cued colors, as discussed above.

Before concluding that only one item can undergo the transformation from a positive template to an exclusionary template – learned distractor rejection – we must demonstrate that this conversion can occur when we explicitly cue one distractor color. To explore this possibility, we removed the ignore cues for one of the two colors. Therefore, we test whether participants can learn to reject one explicitly cued distractor in the presence of a second critical, but non-cued, distractor color. Although we have discussed previous evidence from our lab indicating that multiple distractors can be rejected over the course of an experiment (Vatterott et al., 2018), those previous studies were substantially different from Experiment 1. For example, in our previous work, distractors were highly salient color singletons, making them highly conspicuous nontarget items. The time course of the learned distractor rejection observed with salient singleton distractors is in the order of dozens of trials (e.g., Vatterott & Vecera, 2012), but distractor rejection under explicit distractor cueing can take hundreds of trials to emerge (e.g., Cunningham & Egeth, 2016).

Our aim in Experiment 2 was to determine if learned distractor rejection can occur for multiple distractors in displays and experimental conditions identical to those in Experiment 1, without using explicit distractor cues. Experiment 2 was identical to Experiment 1, except that the cue was always neutral for one of the two critical distractor colors; the other critical distractor color was explicitly cued as in Experiment 1. We predicted that removing the ignore cues for one of the two critical distractor colors should remove the

initial cued distraction that occurs (the “white-bear effect”), affording attention the opportunity to learn implicitly that the color was never predictive of the target. In the absence of an ignore cue, there would be no positive template to create an initial white bear bias; consequently, only an exclusionary template would need to be learned over the course of the experiment. Therefore, no conversion between templates would be required, allowing attention to learn to reject the never-cued distractor. However, for the cued distractor color, we expected to replicate the initial cued distraction cost (the “white-bear effect”). Critically, we were interested in whether participants could learn to reject both distractor colors. Finding distractor rejection to the cued distractor color would replicate previous findings (Cunningham & Egeth, 2016). If attention can indeed reject multiple distractors, one with explicit cueing and the other without, we should observe faster mean RTs on distractor present than distractor absent trials by the end of the experiment. Alternatively, if the participants are incapable of rejecting multiple distractor features through implicit learning – if the explicit cues elicit global interference – then, we should observe initial cued distraction (i.e., slower mean RTs on distractor present than distractor absent trials) followed by no learned distractor rejection (i.e., no difference between mean RTs on distractor present than distractor absent trials).

Method

Participants

We recruited 26 naïve University of Iowa undergraduate students (mean age = 18.6 years; 22 female, four male) from introductory psychology courses with normal or corrected-to-normal visual acuity and normal color vision to participate in the experiment. We stopped data collection at 26 participants, which is consistent with the same power analysis from Experiment 1. Participants gave informed consent and received course credit upon completion. The University of Iowa Institutional Review Board approved the experimental protocol.

Design and procedure

The design and procedure were identical to Experiment 1 except for the following critical change. To measure tuned distractor rejection for one “uncued” (critical) color, all cues for the second, “uncued” color displayed the text “Neutral.” We continued to present Ignore cues before every trial containing the other, explicitly cued distractor color. Neutral/Distractor absent trials were identical to Experiment 1: neither critical distractor was present in the display. All other aspects of Experiment 2 were identical to Experiment 1.

Results and discussion

We removed RTs that were faster than 100 ms, slower than 2,500 ms, and more than 2.5 standard deviations above or below each participant’s condition means, which resulted in the elimination of 4.04% of trials. We further removed inaccurate trials from data analysis, which eliminated 2.37% of all trials. Therefore, we removed 5.90% of all trials. To assess the effect of experience we divided the data into four blocks (160 trials each).

The mean RTs are shown in Fig. 3, which indicates that for the cued color, response times are slower for displays containing the cued-to-ignore distractor color than displays without in Block 1 (“cued distraction” or “white-bear effect”). Further, response times are faster for displays that contain a critical, “uncued” color, that is, a color that is never the target, compared to displays that contain no critical color in Block 4. This finding suggests that learned distractor rejection can only be learned for one, implicitly learned color; explicitly cueing a distractor color leads to cued distraction with no learned distractor rejection. This conclusion was supported by our analyses.

To analyze the effects of experience on the ability to reject both a cued distractor and an “uncued” distractor, we performed a 3 (distractor condition: Ignore vs. Uncued-Present vs. Neutral) $\times$ 4 (block) repeated measures ANOVA on mean RTs. The mean RTs are given in Table 2, and the distraction scores (Cued Effect: ignore trial RTs for the cued color minus neutral trial RTs; Learned Effect: uncued-present trial RTs minus neutral trial RTs) are shown in Fig. 3. As seen in Fig. 3, we observed a robust white bear effect; namely, participants were slowed on ignore trials compared to neutral trials in the first block of the experiment. We did not observe reliable distractor rejection for the cued color, which would appear as negative distraction differences in Fig. 3. However, we did observe reliable distractor rejection for the uncued color in Block 4, which appears as negative distraction differences in Fig. 3.

These observations were corroborated by our statistical analyses. We observed a significant main effect of distractor condition, $F(2,50) = 6.473$, $p = .003$, $\eta_p^2 = .206$, with slower mean RTs on Ignore (968 ms) than Uncued-Present (930 ms) trials (no other differences were significant, all p 's $> .137$); we also observed a significant main effect of block, $F(3,75) = 19.146$, $p < .001$, $\eta_p^2 = .434$, indicating that mean RTs decreased over the course of the experiment. Critically, we observed a significant interaction between distractor condition and block, $F(3,75) = 5.779$, $p < .001$, $\eta_p^2 = .188$. We followed up the interaction by examining the simple main effects of distractor condition for each block. Mean RTs were significantly slower on Ignore (1,097 ms) than on both Neutral (990 ms), $p < .001$, $\eta_p^2 = .501$, and Uncued-Present (998 ms), $p < .001$, $\eta_p^2 = .506$ trials in Block 1; there were no significant

Fig. 3 Experiment 2 results. The differences between mean response times (RTs) for the “Cued Effect” (dark gray bars) on Ignore trials and Neutral trials (Ignore – Neutral/Absent) and the differences between mean RTs for the “Learned Effect” (light gray bars) on Distractor Present – Distractor Absent trials (Present – Neutral/Absent) as a function of Block are plotted. Positive

values indicate increased distraction by the presence of either critical distractor color; negative values indicate increased distractor rejection. Differences are plotted within the bars for convenience. Error bars reflect 95% confidence intervals between the difference scores and zero (Cousineau, 2005; Morey, 2008)

differences in mean RTs between any of the distractor conditions in Block 2, $p = .149$, $\eta_p^2 = .073$, nor any significant differences in Block 3, $p = .606$, $\eta_p^2 = .020$; critically, mean RTs were significantly faster on Uncued-Present (887 ms) than Neutral (935 ms) trials in Block 4, $p = .014$, $\eta_p^2 = .278$; however, mean RTs were not significantly different for any other condition in Block 4, all p 's $> .338$. Therefore, we observed initial distraction to the cued color (“white-bear effect” in Block 1) that disappeared, but did not turn into distractor rejection (Blocks 2–4). Ignore cue trials were not significantly faster than neutral cue trials, in contrast to other work demonstrating efficient distractor rejection (Cunningham & Egeth,

2016; also see Stilwell & Vecera, 2017). Critically, we observed learned distractor rejection for the “uncued” color (Block 4).

Accuracy

We performed the same analysis of accuracy that we used for mean RTs. We performed a 3 (distractor condition: Ignore vs. Uncued-Present vs. Neutral) $\times$ 4 (block) repeated measures ANOVA on mean accuracy. There was no significant main effect of distractor condition, $F(2,50) = 0.520$, $p = .598$, $\eta_p^2 = .020$, but there was a significant main effect of block, $F(3,75) = 4.397$, $p = .007$, $\eta_p^2 = .150$, with mean accuracy being significantly higher in Block 3 (98.2%) than in Block 1 (96.8%), $p = .015$, $\eta_p^2 = .329$; however, there was no significant interaction between distractor condition and block, $F(6,150) = 1.328$, $p = .248$, $\eta_p^2 = .050$. Therefore, our data suggest no speed-accuracy trade-off.

After removing explicit cues for one critical distractor color in the presence of a learned, “uncued” distractor color, the results of Experiment 2 provide evidence that attention is capable of distractor rejection for at least one feature (i.e., color) through experience alone. We observed faster mean RTs on trials containing a critical, “uncued” distractor color than trials

Table 2 Mean response times (RTs; in ms, top half) and accuracy (lower half) for Experiment 2. Standard deviations are given in parentheses

Trial type	Block 1	Block 2	Block 3	Block 4
Ignore (RT)	1097 (403)	940 (323)	912 (287)	922 (328)
Uncued-Present (RT)	998 (361)	904 (318)	931 (301)	887 (316)
Neutral (RT)	990 (346)	935 (331)	929 (310)	935 (328)
Ignore (Acc.)	97% (.13)	98% (.09)	99% (.07)	97% (.11)
Uncued-Present (Acc.)	97% (.15)	98% (.09)	98% (.08)	98% (.10)
Neutral (Acc.)	97% (.13)	97% (.12)	98% (.09)	98% (.09)

without (Block 4). These results conceptually replicate learned distractor rejection during feature-search (e.g., Vatterott & Vecera, 2012; Vatterott, et al., 2018). However, attention cannot learn to reject an explicitly cued distractor color in the presence of an additional, “uncued” learned distractor color: We observed slower mean RTs on trials containing an explicitly cued distractor color than on trials without. These results replicate previously observed cued distraction effects (e.g., Cunningham & Egeth, 2016) as well as the pattern observed for both cued colors in Experiment 1 of the current study. We again observed reliable cued distraction effects (the “white-bear effect”) for the cued color that did not transition to learned distractor rejection.

Experiment 3

Having failed to observe distractor rejection for two explicitly cued distractor features in Experiment 1, and for one explicitly cued distractor feature in the presence of an “uncued” distractor feature in Experiment 2, we suggest that the lack of distractor rejection with multiple cued colors is unlikely to be due to a capacity limitation on the number of items that can be ignored. Instead, we hypothesize that explicit cues get in the way of effective distractor rejection because the presence of a color word in the cue initially biases attention toward matching items, and some other process must flip or negate this bias. This changeover between biases has been conceptualized as a conversion from a positive template to an exclusionary template, or template for rejection (see Beck et al., 2018).

Before concluding that only one item can undergo the transformation from a positive template to an exclusionary template, we must demonstrate that multiple distractors can indeed be rejected under the same displays and conditions employed in Experiment 1. In Experiment 2, we found reliable learned distractor for the “uncued” distractor feature, therefore the visual attentional system is capable of learning to reject – capable of forming an exclusionary template for – at least one consistent distractor feature through experience. Although we have discussed previous evidence from our lab indicating that multiple distractors can be rejected over the course of an experiment (Vatterott et al., 2018), those previous studies were substantially different from Experiment 1. For example, in our previous work, distractors were highly salient color singletons, making them highly conspicuous nontarget items. The time course of the learned distractor rejection observed with salient singleton distractors is in the order of dozens of trials (e.g., Vatterott & Vecera, 2012), but distractor rejection under explicit distractor cueing can take hundreds of trials to emerge (e.g., Cunningham & Egeth, 2016).

Our aim in Experiment 3 was to determine if learned distractor rejection can occur for multiple distractors in

displays and experimental conditions identical to those in Experiment 1, without using explicit distractor cues. Experiment 3 was identical to Experiment 1, except that the cue was always neutral. We predicted that removing the ignore cues should remove the initial distraction incurred (the “white-bear effect”), affording attention the opportunity to learn implicitly which colors are distractors and which are not. In the absence of an ignore cue, there would be no positive template to create an initial white bear bias; consequently, only an exclusionary template would need to be learned over the course of the experiment. Therefore, no conversion between templates would be required, allowing attention to learn to reject multiple distractors. If attention can indeed reject multiple distractors without explicit ignore cueing, we should observe faster mean RTs on distractor present than distractor absent trials. Alternatively, if the system is incapable of rejecting multiple distractor features through implicit learning, then we should observe no such learned distractor rejection (i.e., no difference between mean RTs on distractor present than distractor absent trials).

Method

Participants

We recruited 26 naïve University of Iowa undergraduate students (mean age = 18.9 years; 18 female, eight male) from introductory psychology courses with normal or corrected-to-normal visual acuity and normal color vision to participate in the experiment. We stopped data collection at 26 participants, which is consistent with the same power analysis from Experiment 1. Participants gave informed consent and received course credit upon completion. The University of Iowa Institutional Review Board approved the experimental protocol.

Design and procedure

The design and procedure were identical to Experiment 1 except for the following critical change. To measure tuned distractor rejection for two “uncued” (critical) colors, all cues displayed the text “Neutral,” thus, search displays were identical to Experiment 1, and participants would have to learn that the target was never one of the two critical colors. When either critical color was presented (as a majority color), the target could not be this color, throughout the experiment. As in Experiment 1, when the critical color was presented as a majority distractor, the target could never be this color. Half of all trials contained one of the two critical colors (25% of all trials contained each as a majority distractor color), and the remaining half of all trials were neutral, in that they did not contain either critical color. All other aspects of the design were identical to Experiment 1.

Results and discussion

We removed RTs that were faster than 100 ms, slower than 2,500 ms, and more than 2.5 standard deviations above or below each participant's condition means, which resulted in the elimination of 3.13% of trials. We further removed inaccurate trials from data analysis, which eliminated 3.22% of all trials. Therefore, we removed 6.35% of all trials. To assess the effect of experience we divided the data into four blocks (160 trials each).

The mean RTs are shown in Fig. 4, which indicates that response times are faster for displays that contain a critical color, that is, a color that is never the target, compared to displays that contain no critical color. This finding suggests that learned distractor rejection can be learned for two distractor colors that appear on different trials. This conclusion was supported by our analyses. We performed a 2 (distractor condition: One vs. Neither) $\times$ 4 (block) repeated measures ANOVA on mean RTs, again collapsing across the two distractor colors because initial analyses found no differences among the colors. We observed a marginally significant main effect of distractor condition, $F(1,25) = 3.768$, $p = .064$, $\eta_p^2 = .131$, with numerically faster mean RTs on One Distractor (872 ms) than Neither Distractor (889 ms) trials; we also observed a significant main effect of block, $F(3,75) = 17.019$, $p < .001$ (Huynh-Feldt corrected), $\eta_p^2 = .405$, indicating that mean RTs decreased over the course of the experiment. We failed to observe a significant interaction between distractor condition and block, $F(3,75) = .756$, $p = .522$, $\eta_p^2 = .029$. We performed planned comparisons between distractor condition and block to see if learned distractor rejection developed over time. There was no difference between mean RTs on One Distractor (B1 – 949 ms, B2 – 865 ms, B3 – 852 ms) and Neither Distractor (B1 – 959 ms, B2 – 874 ms, B3 – 870 ms) trials for Blocks 1–3, (all p 's $> .261$); however, mean RTs were significantly faster on One Distractor (822 ms) than Neither

Distractor (854 ms) trials in Block 4, $p = .004$, $\eta_p^2 = .289$. Therefore, we observed learned distractor rejection for uncued colors, but learning was slow to develop.

Individual color analyses

To examine whether participants were rejecting both distractor colors, or only rejecting one color at a time, we conducted follow-up analyses that were similar to those reported in Experiment 1. To be clear, the possibility remains that some participants only learned to reject one of the two colors, thus, if participants were only learning to reject one color at a time, with some participants learning to reject one color, and other participants learning to reject the other color, our prior analyses, specifically the interaction between distractor condition (i.e., a distractor color present vs. no distractor color present) and block was doomed to fail. This interaction would only be significant if participants happened to all reject the *same* color.

To address this concern, we determined which of the two colors, for each participant, was the more interfering color (i.e., the color that produced slower mean RTs when it was present than absent) and which color was the less interfering color (i.e., the color that produced faster mean RTs when it was present than absent): less interference equates to more distractor rejection. After identifying the more and less interfering colors, respectively, for each participant, we then performed a one-way, repeated measures ANOVA with three conditions (distractor condition: more interfering color present vs. less interfering color present vs. neither distractor color present) on mean RTs in Block 4 only (the block with reliable distractor rejection). We observed a significant main effect of distractor condition, $F(2,50) = 6.209$, $p = .004$, $\eta_p^2 = .199$, which was driven primarily by faster mean RTs on trials containing the less interfering color (803 ms) than trials without either distractor color present (854 ms), $p = .001$. All other differences were not significant (all p 's $> .118$). This analysis

Fig. 4 Experiment 3 results. Mean response times (RTs) for each condition, neither distractor color present (lighter gray line: “Neither Distractor Color”), and one distractor color present (darker gray line:

“One Distractor Color”), as a function of Block are plotted. Error bars reflect within-subject 95% confidence intervals (Cousineau, 2005; Morey, 2008)

initially suggests that participants selected one of the two colors to ignore and learned to reject only that color. However, the finding that there was no difference between the more interfering color distractor and the less interfering color distractor is inconclusive and indicates that participants might reject both distractors, although to different degrees. We return to this point below (Table 3).

Accuracy

We performed the same analysis of accuracy that we used for mean RTs. We performed a 2 (distractor condition: One vs. Neither) $\times$ 4 (block) repeated measures ANOVA on mean accuracy. There was neither a significant main effect of distractor condition, $F(1,25) = 1.502$, $p = .232$, $\eta_p^2 = .057$, of block, $F(3,75) = 1.305$, $p = .279$, $\eta_p^2 = .050$, nor a significant interaction between distractor condition and block, $F(3,75) = .191$, $p = .868$ (Huynh-Feldt corrected), $\eta_p^2 = .008$. Therefore, our data suggest no speed-accuracy trade-off.

After removing explicit cues, the results of Experiment 3 provide evidence that attention is capable of distractor rejection for at least one feature (i.e., color) through experience alone. We observed faster mean RTs on trials containing a critical distractor color than trials without. However, though we observed numerically faster mean RTs on distractor present than distractor absent trials, the main effect of distractor presence was marginally significant. We did observe significantly faster mean RTs by the end of the experiment (Block 4) for distractor present than distractor absent trials. The effects of learned distractor rejection, in feature-search, likely take longer to emerge. Our results conceptually replicate others in the literature (Gaspelin, et al., 2017; Vatterott & Vecera, 2012; Vatterott, et al., 2018), where learned distractor rejection takes time to develop. Critically, the literature has examined learned distractor rejection when the distractor is more salient, that is, when the critical distractor is a salient singleton. Perhaps, with less salient distractors, as in our design, the system takes longer to extract the distractor regularities and establish control settings for rejection. Therefore, if we give the system more opportunities to learn which features can be safely ignored, we might see distractor rejection emerge within the course of our design.

Our individual color analyses appear to suggest that attention could only learn to reject one distractor feature. We found significantly faster mean RTs when the less interfering color

was present than when no distractor color was present (learned distractor absent trials). However, by definition because of the analyses we performed, mean RTs would be different for the more and less interfering colors (i.e., mean RTs for the less interfering would be faster than mean RTs for the more interfering color); thus, these analyses may represent the artifactual division of the two conditions and not distractor rejection. To overcome this ambiguity, we introduced displays containing both learned distractor colors.

Experiment 4

In Experiment 3, we observed learned distractor rejection to multiple distractor features without the use of explicit cues. Based on our secondary analysis examining one versus two colors, our results appeared to be driven more by one of the two learned distractor colors. To conclude that attention is capable of learning to reject multiple distractor features, we would need to more conclusively demonstrate that participants were learning to reject *both* distractor colors. Therefore, the purpose of Experiment 4 was to determine if attention showed a gain in improvement when both distractors appeared in a display. If individual participants rejected only one of the two distractor colors, then there should be no advantage to having both distractors appear in a display. In Experiment 4, we added trials in which both distractor colors appeared to ask if attentional search would benefit from both distractor features simultaneously. In Experiment 3, each distractor feature was presented in isolation. In Experiment 4, trials could contain both distractor features; thus, we predicted the system would use both sources of information to further reduce the effective set size. This slight change in Experiment 4 allows us to replicate learned distractor rejection for more than one distractor color and to determine if increased exposure to the distractor colors increases either the rate of learned distractor rejection, the magnitude of this rejection, or a combination of the two. This design also added participants' exposure to each of the distractor colors, addressing the possibility that more instances of multiple distractors must occur to ensure robust distractor rejection.

Method

Participants

We recruited 26 naïve University of Iowa undergraduate students (mean age = 18.2 years; 18 female, eight male) from introductory psychology courses with normal or corrected-to-normal visual acuity and normal color vision to participate in the experiment. We stopped data collection at 26 participants, which is consistent with the same power analysis from Experiment 1. Participants gave informed consent and

Table 3 Mean accuracy for Experiment 3. Standard deviations are given in parentheses

Trial type	Block 1	Block 2	Block 3	Block 4
One distractor (Acc.)	97% (.13)	96% (.14)	97% (.13)	96% (.16)
Neither distractor (Acc.)	97% (.14)	97% (.14)	97% (.15)	96% (.15)

Fig. 5 Experiment 4 results. Mean response times (RTs) for each condition, neither distractor color present (lighter gray line: “Neither Distractor Color”), one distractor color present (darker gray line: “One Distractor

Color”), and both distractor colors present (black line: “Both Distractor Colors”), as a function of Block are plotted. Error bars reflect within-subject 95% confidence intervals (Cousineau, 2005; Morey, 2008)

received course credit upon completion. The University of Iowa Institutional Review Board approved the experimental protocol.

Design and procedure

The design and procedure were identical to Experiment 3 except for the following critical change. To test whether having both sources of “uncued” information would improve distractor rejection, we included displays where both critical colors were present together. Therefore, 25% of all trials contained one critical color, 25% of all trials contained the other critical color, 25% of all trials contained both critical colors, and 25% of all trials had neither critical color present. When both critical colors were present, each majority color was each critical color (six items were the critical colors, three items rendered in each color), thus, the target would only appear in one of the two heterogeneously colored items. All other aspects of the experiment were identical to Experiment 3.

Results and discussion

We removed RTs that were faster than 100 ms, slower than 2,500 ms, and more than 2.5 standard deviations above or below each participant’s condition means, which resulted in the elimination of 2.84% of trials. We further removed inaccurate trials from data analysis, which eliminated 1.26% of all trials. Therefore, we removed 4.1% of all trials. To assess the effect of experience we divided the data into four blocks (160 trials each).

Any distractor’s presence

To demonstrate a replication of the pattern observed in Experiment 3, we collapsed trials with displays containing

any distractor color, and compared them to displays containing no distractors: these mean RTs are shown in Fig. 4. This pattern of results mirrors what we observed in Experiment 3 and suggests learned distractor rejection can occur for two distractor colors. This conclusion was supported by our analyses. We performed a 2 (distractor condition: Any vs. Neither) $\times$ 4 (block) repeated measures ANOVA on mean RTs. We observed a main effect of block, $F(3,75) = 19.350$, $p < .001$, $\eta_p^2 = .436$, indicating that mean RTs decreased over the course of the experiment. Critically, we observed a main effect of distractor condition, $F(1,25) = 8.849$, $p = .006$, $\eta_p^2 = .261$, demonstrating a reliable benefit for mean RTs on trials that contained a distractor color (Any: 897 ms) than on trials that did not contain a distractor color (Neither: 933 ms). The interaction between distractor condition and block failed to reach significance, $F(3,75) = 1.930$, $p = .132$, $\eta_p^2 = .072$.

All distractor conditions

The mean RTs are shown in Fig. 5, which indicates that RTs are fastest for displays that contain both learned distractor colors, next fastest for displays containing one of the learned distractor colors, and slowest for displays containing neither learned distractor color. We performed a 3 (distractor condition: One vs. Both vs. Neither) $\times$ 4 (block) repeated measures ANOVA on mean RTs.² We observed a significant main effect of distractor condition, $F(1,25) = 6.738$, $p = .007$ (Huynh-Feldt corrected), $\eta_p^2 = .212$. We performed follow-up,

² We collapsed the two one distractor conditions, because we performed a 2 (distractor type: Uncued 1 vs. Uncued 2) $\times$ 4 (Block) repeated measures ANOVA on mean RTs. Critically, we found no main effect of distractor type, $F(1,25) = .034$, $p = .855$, nor a significant interaction between distractor type and block, $F(3,75) = 2.138$, $p = .103$, indicating that there was no difference between the two uncued distractor conditions, allowing us to collapse across both.

pairwise comparisons, where we observed significantly faster mean RTs on One Distractor (902 ms), $p = .026$, and on Both Distractors (886 ms), $p = .029$, than on Neither Distractor (933 ms) trials. We did not find significant difference between mean RTs between the One Distractor and Both Distractors trials, $p = .358$ (all p 's corrected using the Dunn-Sidak method). We observed a significant main effect of block, $F(3,75) = 22.791$, $p < .001$, $\eta_p^2 = .477$, indicating that mean RTs decreased over the course of the experiment. Additionally, we observed a significant interaction between distractor condition and block, $F(3,75) = 2.438$, $p = .028$, $\eta_p^2 = .089$.

One versus two colors

To examine whether participants were just learning to reject one color instead of both, as the results of Experiment 3 seem to suggest, we analyzed trials containing both distractor colors versus trials containing only one. As evident in Fig. 5, mean RTs were faster on trials containing both distractor colors were present than trials containing only one distractor color. This pattern was corroborated by our analyses. We performed a 2 (distractor condition: One vs. Both) $\times$ 3 (Blocks 2–4) repeated measures ANOVA on mean RTs. We only examined Blocks 2–4 because individuals would first have to learn to reject the colors, therefore, we would expect no difference in Block 1, as is evident in Fig. 5 (and in Experiments 2 and 3 for uncued distractors). We observed a main effect of distractor condition, $F(1,25) = 4.896$, $p = .036$, $\eta_p^2 = .164$, with faster mean RTs on trials containing both distractor colors (858 ms) than trials containing only one distractor color (885 ms); a main effect of block, $F(2,50) = 11.049$, $p < .001$, $\eta_p^2 = .306$, indicating that participants became faster at the task over time; but critically, we failed to observe a significant interaction between distractor condition and block, $F(2,50) = 0.147$, $p = .863$, $\eta_p^2 = .006$, indicating that the benefit of having both distractors present in the display did not change as a function of block. Importantly, these analyses demonstrate that participants learned to reject *both* colors, over and above either color alone.

Accuracy

Participants' accuracy was very high, as shown in Table 4. We performed the same analysis of accuracy that we used for mean RTs. We performed a 3 (distractor condition: One vs. Both vs. Neither) $\times$ 4 (block) repeated measures ANOVA on mean accuracy. There was neither a

significant main effect of distractor condition, $F(1,25) = .782$, $p = .463$, $\eta_p^2 = .030$, of block, $F(3,75) = .150$, $p = .929$, $\eta_p^2 = .006$, nor a significant interaction between distractor condition and block, $F(3,75) = .389$, $p = .849$ (Huynh-Feldt corrected), $\eta_p^2 = .015$. The lack of any effect in the accuracy data likely reflects a ceiling effect because of participants' overall high accuracy.

In Experiment 4, we gave the visual attentional system more practice with distractor rejection by increasing exposure to reliable distractor color information: We included displays where both distractor colors were presented together. Our manipulation of critical distractor color exposure, lead to reliable learned distractor rejection effects which emerged sooner than Experiment 3. The results of Experiment 4 suggest that individuals extracted the reliable distractor color information early (by Block 2) and used the extracted information to establish distractor rejection control settings: mean RTs were reliably faster when distractor colors were present than when they were absent.

The current findings support the results from Experiment 3 and indicate that participants can learn to reliably reject multiple distractor features through experience alone, consistent with previous results (Vatterott et al., 2018). We found a reliable benefit for having at least one distractor present in the display than having neither distractor present. Additionally, our results, specifically the analysis comparing displays containing both distractor colors to displays containing only one, support the notion that the system benefits from having *both* learned distractor colors. Mean RTs were significantly faster when both distractor colors were present than when only one distractor color was present. Further, the results of Experiment 4 demonstrate that participants learned to reject both distractor features, which is evident in the added benefit of having both distractor colors in the display compared to only having one. These results – reliable, *learned* distractor rejection for multiple distractor colors – contrast the pattern of results observed for explicitly *cued* distractors, where attention seems incapable (at least within the time-course we've examined) of distractor rejection for multiple distractor colors.

Table 4 Mean accuracy for Experiment 4. Standard deviations are given in parentheses

Trial Type	Block 1	Block 2	Block 3	Block 4
One Distractor (Acc.)	99% (.05)	99% (.05)	99% (.05)	99% (.06)
Both Distractors (Acc.)	98% (.09)	98% (.08)	99% (.06)	98% (.09)
Neither Distractor (Acc.)	99% (.06)	99% (.06)	98% (.08)	98% (.08)

However, our observed, learned, distractor rejection for multiple features parallels other results in the literature for singleton distractors (Vatterott, et al., 2018).

General discussion

In four experiments, we tested the role of reliable distractor cues versus learned distractor information on the guidance of visual attention in a visual search task. In Experiment 1, we demonstrated that visual attention was incapable of rejecting as few as two distractor colors when those distractors were explicitly cued. In the first block of trials, participants' mean RTs were reliably *slower* when the distracting features were present (Ignore trials) than absent (Neutral trials). This pattern of distraction conceptually replicates the cued distraction effect (e.g., the “white-bear effect”, Cunningham & Egeth, 2016). Interestingly, the pattern of distraction never reversed to produce reliable distractor rejection, also paralleling previous findings from cued distractor rejection (Cunningham & Egeth, 2016).

In Experiment 2, we demonstrated that learned distractor rejection was possible for a distractor color that was never explicitly cued, yet could be consistently ignored. In the last block of the experiment, participants' mean RTs were reliably *faster* when the consistent, “uncued” distractor color was present (“Uncued” Distractor Present trials) than when it was absent (“Uncued” Distractor Absent trials). Conversely, we demonstrated that visual attention cannot learn to reject an explicitly cued color in the presence of an additional, learned distractor color. Early in the experiment, participants' mean RTs were reliably *slower* when the cued-to-ignore distractor feature was present (Ignore trials) than when it was absent (Neutral trials). This cued distraction replicates the pattern observed in Experiment 1, and previous findings (e.g., the “white-bear effect”, Cunningham & Egeth, 2016). The results of Experiment 2 are consistent with Experiment 1, demonstrating initial cued distraction that never turned into learned distraction rejection. Critically, we did establish that visual attention is capable of learning to reject a consistent distractor feature through experience alone.

Further, in Experiment 3, we used the same design as in Experiment 1, but, we removed the informative ignore cue. Therefore, we maintained equal exposure to the distractors, but the distractors' colors were never explicitly cued. The results of Experiment 3 suggested that without explicit ignore cues, and critically without the initial white-bear distraction effect, participants learned the

distractors' colors and could reject multiple distractor features when they were present in a display. Mean RTs were *faster* when the critical distractor colors were present than when they were absent, a hallmark of distractor rejection through suppression (see Gaspelin et al., 2015). These results suggest that visual attention is capable of learning to reject multiple, *non-salient* distractor features, replicating the pattern observed in Experiment 2, and extending published results on learned distractor rejection (Vatterott & Vecera, 2012; Vatterott et al., 2018). Importantly, learned distractor rejection is slow to emerge in the relatively demanding search task used in the current experiments, as reliable effects did not emerge until Block 4. This point is discussed further below.

Experiment 4 examined whether participants can learn to reject multiple distractor colors in a different way. We added a condition in which both distractor colors were present simultaneously. The results of Experiment 4 replicate and extend the pattern of Experiments 2 and 3. First, we observed reliable distractor rejection by Block 2, which persisted throughout the remaining trials, evidenced by faster mean RTs on trials containing any critical distractor color than trials with no distractor color present. Next, we also observed a trending pattern that having both critical distractor colors in the display simultaneously provided an added benefit than having either critical distractor color alone. Mean RTs were significantly faster when *both* distractor colors were present than when only *one* distractor color was present.

Our present results appear to rule out a general limitation for the number of items that can be rejected. Participants can only learn to reject one feature at a time through explicit cueing (Cunningham & Egeth, 2016). However, participants can readily reject multiple distractors if the non-target distractor colors are learned implicitly over the course of the experiment, without any direct cueing or summoning of attention toward those distractor colors. Explicitly cueing a distractor leads to the counterproductive effect of drawing attention to that feature, which results likely because either the distractor's features have been directly activated or primed when the distractor itself is shown as a cue (see Arita et al., 2012; Moher & Egeth, 2012, for examples) or because of the strong association between a color word that appears as a cue (“Ignore Red”) and the distractor's features. We are unsure regarding whether this activation arises in visual short-term memory or through activated associations with visual long-term memory. In either case, the presentation of a distractor cue has the potent effect of establishing a representation that biases attention toward matching items, despite the task's structure and instructions to the contrary.

To optimize search performance, participants must somehow overcome the bias toward the cued distractor and, ideally, develop a bias away from that distractor. Rejecting or deprioritizing cued distractors likely occurs through converting the cued distractor feature to a spatial map or template when the search array appears; this spatial map for rejection can then, given sufficient time, aid attention in avoiding the locations occupied by the cued distractor (see Beck & Hollingworth, 2015; Kugler et al., 2015). Implementing this spatial map for distractor rejection appears to be facilitated by spatially segregated displays. Deprioritizing and suppressing a cued distractor can be performed rapidly if search arrays are spatially segregated by color (Arita et al., 2012; Beck & Hollingworth, 2015).

However, there was no spatial segregation in either the search displays in the current experiments or those in Cunningham and Egeth (2016). Instead, cued distractors that are stable and consistent across the course of the experiment appear to allow a spatial rejection map to be created and implemented even for unorganized arrays. Such consistent cued distractors allow task regularities to be learned, possibly helping to speed the formation or implementation of the map for rejection, as observed in some tasks that track the time course of trial-unique distractor rejection (Beck et al., 2018; Moher & Egeth, 2012).

However, merely adding a second cued distractor clearly disrupts the support from longer-term learning, as we demonstrated in Experiment 1. One possible explanation for this loss of distractor rejection is that adding a second cued distractor eliminates learning through catastrophic interference, in which to learn one cued distractor implies un-learning the other cued distractor. This account, however, does not readily explain the results of Experiments 3 and 4 or other findings in the literature (Gaspelin & Luck, 2017; Gaspelin, et al., 2017; Vatterott & Vecera, 2012; Vatterott et al., 2018). Further, in Experiment 2, we demonstrated the same cued distractor interference, despite only cueing one distractor feature. If participants were un-learning the other cued color in Experiment 1, then they should not have learned to reject the second, “uncued” distractor color in Experiment 2. Alternatively, adding a second cued distractor color could interfere with or prevent the creation and implementation of the spatial map used for rejection. Some accounts claim that attentional guidance toward targets is limited to a single item (see Olivers et al., 2011), although there is ample evidence that supports attentional guidance toward targets

by multiple templates (Beck & Hollingworth, 2017; Beck et al., 2012; Irons, Folk, & Remington, 2012; Moore & Weissman, 2010; Roper & Vecera, 2012). Aligning these views with the current results, multiple target templates might be possible because such templates require only maintenance in memory. In contrast, using a distractor cue might involve manipulation in memory to deprioritize the cued distractor color and create a map for rejection. Such manipulation in memory might impose a substantial cognitive demand which limits the number of distractors that can be rejected and which limits the learning of consistent distractors across an experiment.

An additional point for discussion is why learned distractor rejection appears to emerge more slowly in our experiments than in Vatterott et al. (2018). One likely explanation is that the current experiments’ distractors were not distinct color singletons, making it harder for the attentional system to initially sample the distractors to learn their status as non-targets. When the distractors are more salient (Gaspelin et al., 2015; Vatterott & Vecera, 2012; Vatterott et al., 2018), attention likely detects the feature regularities faster because of the distractor’s salience. However, in our experiments the distractors are no more physically salient than any other colored item in the display, making it more challenging for the system to extract the reoccurring distractor feature regularities.

Dominant accounts of visual attention and visual search have relied on a target template held in visual short-term memory for the guidance of attention (e.g., Bundesen, 1990; Desimone & Duncan, 1995; Wolfe, 1994), and the initial studies of distractor rejection also focused on how short-term or trial unique information can support distractor rejection. However, our environments contain many regularities that can guide attention (see Kunar, Flusberg, Horowitz, & Wolfe, 2007), and context can determine where visual attention is deployed (e.g., Chun & Jiang, 1998) and even the type of attentional search employed (Cosman & Vecera, 2013). The current results suggest that attention may be better suited to learn distractor rejection, particularly for multiple distractors, through implicit (uncued) experience alone, relying on statistical learning to extract those distractor features that are reliably present, rather than rejecting distractors through explicit, cued instructions.

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